CONSTRUCTION/DEMOLITION WOOD AS FUEL FOR COFIRING

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INTRODUCTION

National interest in the combustion of wood and wood/coal mixtures is growing rapidly in response to the world-wide concern for global warming, the U.S. concern for SO_2 and NO_x emissions, and regional interest in expanding the utilization of forest products and byproducts. The wood/coal cofiring program at the University of Pittsburgh has focused its early work on the use of clean urban waste. A design requirement of the program was that the cofiring be accomplished by providing a wood-coal fuel blend that could be utilized by the boilerhouses as a regular fuel shipment without modification or capital expenditures. Three demonstrations of cofiring wood and coal, up to 12% wood by BTU content, have been conducted at two local boilerplants. The first project, conducted in 1997, under this program was a demonstration at the traveling-grate stoker boiler of a Pittsburgh Brewing Company (PBC)[1]. In May 1999, a second demonstration was completed at a federally owned spreader stoker operated by the National Institute of Occupational Safety and Health (NIOSH)[2]. The third demonstration was conducted at PBC in October 1999. The principal wood used in all the demonstrations was broken pallets tub-ground to a mulch-like in its consistency. Combustion has been very acceptable, but further development work is underway to achieve acceptable feeding characteristics of the mixture through the receiving grill and pit of the boilerplants. The prime objective of the University of Pittsburgh's wood/coal cofiring program is the successful introduction in western Pennsylvania of commercial cofiring fuel for stoker boilers. This paper summarizes the results of the demonstrations at PBC and NIOSH along with observations on the identification of specific sources of urban wood, and the processing required to produce a cofiring fuel.

PROJECT DESCRIPTION

PBC Demonstration I Steam for brewing, bottling and space heating is produced at the boilerhouse, which contains a gas-fired boiler and two traveling-grate stokers. The stokers are rated at 42,000 lb steam/hr (140 psig) and do not have emissions control equipment. Allegheny County Health Department (ACHD) has primacy for air quality assurance. ACHD generally requires that coal-fired boilers (above 0.5 MMBtu/hr thermal input) emit less than 1.2 lb/MMBtu of SO_2 with an allowable opacity of less than 20%. ACHD performs visible inspections of stack plumes to check opacity and ensure that boilerhouses do not become nuisance problems for neighbors. Stoker coals used in Allegheny County usually arrive by river barge from low-sulfur mines in the Virginia/West Virginia/Kentucky region. Such low-sulfur, stoker-sized coals can cost up to $56/ton when delivered to the boilerplants.

Junior pea stoker coal - ¾ inch by ¼ inch - is delivered to the PBC by tri-axle truck (25 tons) from the Colona Terminal, a transfer station twenty miles west of the plant. Coal is dumped directly into a feed pit, which has a bucket elevator to convey the coal to one of two day bins located above the operating boiler. The feed pit is covered by a grizzly, for vehicle and personnel access, with openings of about 7-inches square. A paddle wheel feeder directs coal from the pit to the bucket elevator, which then transports it to the chute that supplies the day bin. Two chutes of about two feet square convey at the fuel from the day bin to a small hopper. Fuel is then fed by gravity from the small, open hopper onto the traveling grate that has an adjustable gate to set the initial fuel bed height above the grate. The fuel firing rate, set by the grate speed, is determined by a Bailey PID controller.

The first wood obtained for testing was screened tub-ground pallet pieces. Early in the test program, the size consist of this material was 1¼ inch by zero, but later it was changed to 1¼ inch by ¼ inch. The test was expanded to include a second urban wood waste – a 1 inch by zero chipped clearance wood. Fifteen 3-4 hour tests of 5% to 40% wood fuel blends (by volume) were conducted to evaluate the fuel flow/handling characteristics with PBC's existing conveying system. The blended fuels were prepared from wood and coal stored in two open piles near the boilerhouse, using a small front-loader bucket to assist with mixing, before the coal/wood fuel blends were loaded into the day bin. In addition, several 24 hour tests and a 72 hour test with flue gas monitoring provided by the Federal Energy Technology Center (FETC) were conducted to evaluate the boilerplant's ability to operate at steady state with a wood/coal mixture. These mixtures were prepared at Colona Terminal by layering the coal and wood onto the bed of a regular tri-axle delivery truck.

NIOSH Demonstration The NIOSH boilerhouse produces steam for the center's district heating system. The boilerhouse contains two gas-fired boilers and a spreader stoker Keeler boiler. The boiler is rated at 55,000 pph at 200 psig (but normally operates at 100 psig) with a baghouse for emissions control. As at PBC, ACHD has primacy for air quality assurance at the boilerplant and requires the use of low-sulfur compliance coal.

The junior pea stoker coal comes by barge from eastern Kentucky to a transfer station on the river and is trucked from the transfer station to the plant in 25-ton loads. Coal is dumped directly into a receiving hopper. The coal receiving hopper is situated below a steel grate with openings a minimum of 5" by 8". A Syntron coal feeder picks up the coal onto a belt conveyer, which takes the coal up an elevation of 20 feet to a bucket elevator. The bucket elevator elevates the coal six stories to hoppers. From these hoppers the coal goes down through ducts onto a horizontal paddle conveyer that unloads the coal into a bunker. There are twelve gates at the bottom of the bunker. Another horizontal conveyer receives the coal from any one of the selected gates and delivers the coal to the Detroit Roto Grate stoker spreader feeder system.

There are three 18" feeders with a capacity of 500 to 2000 pounds per hour each. The boiler is also designed with an overfire air system to reburn the flyash. The stokers throw the coal to the back of the boiler, while a moving grate travels from back to front. The coal burns both above the grate in suspension and on the grate. A large number of fine fuel particles leave unburned from the firebox. The finer particles go through the economizer while the heavier ones are reinjected into the boiler by a stream of over fire air. The bottom ash falls into a hopper.

The wood for all test burns was a nominal 1¼ inch by ¼ inch tub-ground pallet waste. The screen and outlet of a tub grinder were modified from the settings used in the PBC demonstration to produce more "chunks" and fewer "stringers" from that used at PBC. Four-hour test burns of 10%, 20%, 30% and 40% wood by volume were conducted in mid-May 1999. The 10% and 20% wood fuel blends were prepared by mixing the wood and coal on the pad, while the 30 and 40% blends were prepared by layering the coal and wood onto the bed of the delivery truck. A 48-hour test burn was conducted using a fuel blend of approximately 33% wood by volume.

PBC Demonstration II In October 1999, two 4-ton mixtures of wood/coal fuel blend were test fired in one of PBC's stoker boilers. The wood component of the fuel blend was prepared by a modified method that produced a more cubic wood particle. Additionally, the wood and coal were mixed at the wood processor's site with a with a FECON blender to 50% wood by volume or about 12% by BTU content.

ACCOMPLISHMENTS

Fuel Conveyance: PBC Demonstration The demonstration showed that fuel conveyance plays a critical role in the ability of a stoker boiler to handle and feed wood/coal blends. With the exception of a few large pieces, the flow properties of the wood chip/coal blends was similar to junior pea stoker coal. The same held true for the flow properties of the tub-ground wood/coal mixture when properly mixed at relatively low wood percentages.

The critical bottleneck for handling fuel blends with a tub-ground wood content greater than approximately 33% occurred at the grizzly and feed pit. First, the fuel blend bridged the openings in the grizzly to the point that regular intervention was required to maintain flow. Intervention by the operators was acceptable to the manager of this plant. Second, transport of the fuel blend from the feed pit to the entrance of the bucket elevator was erratic and required occasional prodding to sustain flow.

In the initial stages of the first demonstration at PBC, a second problem with conveyance developed. The second, and more important, effect was on fines segregation in the bin. A mixture of wood and coal fines built up rapidly in the day bin. When the pile of fines slumped, a "plug" of fines passed down the chutes and eventually onto the grate, causing significant adverse shifts in burning characteristics, especially when the fuel was soaking wet.

Two adjustments to fuel preparation were made to limit this second problem. The tub-ground material received a second bottom screening to reduce fines, and the method of blending wood/coal mixture was altered. In early tests, the wood and coal were mixed on the ground with a front-end loader to ensure that homogeneous mixture would be delivered. However, this method crushed the coal somewhat and generated excess coal fines. After this problem was recognized, coal and wood were layered onto the truck without any mixing. It was then observed that conveyance through the PBC system components mixed the wood/coal sufficiently while reducing fines production.

At all wood/coal percentages, the green wood chips, when free of large pieces and "plates", flowed through the conveyance system in a manner similar to the stoker coal, with no observed change in fines segregation. However, the wood chips delivered to both PBC and the terminal did contain a small number of long, thin pieces (up to several feet long) and plate-like chips (up to eight inches across). The material delivered to PBC had to be hand-sorted before blending with coal to prepare a mixture that would pass through the grizzly and paddlewheel feeder. Such sorting was not possible in preparing fuel at Colona terminal. The grizzly acted as a screen for oversized pieces that required heavy manual effort for removal. The oversized pieces were attributed to operating problems with the chipper, which should be corrected with proper adjustment.

Fuel Conveyance: NIOSH Demonstration Just as in the PBC demonstration, the NIOSH demonstration showed that fuel conveyance plays the critical role in the ability of a stoker boilerplant to utilize a wood/coal fuel blend. The wood used was principally mulch-like. Long stringers had been screened out as planned, but the grinder had not yet been refitted to produce principally chip-like material, rather than mulch-like material. This led to a difference between expected and delivered processed wood to the project. The resulting wood/coal blend did flow reasonably well from the bunker to the boiler, and it burned well in the boiler; but it needed considerable assistance to pass through the grate into the outside fuel-receiving hopper. Providing this assistance is unacceptable to this plant's superintendent.

Combustion Both at PBC and at NIOSH, once fed to the grate, properly prepared wood/coal mixtures of both ground pallets and green wood chips met the demonstration's goals for combustion characteristics. As expected, there were no occurrences of flame propagating back into the fresh fuel across the gate, or discharge of still-burning ash particles into the ash pit or out of the boiler during any test.

Compared to coal, wood is a high volatile, low heat content and low density fuel. The lower heat content of the wood can be compensated for by a higher rate of feed (on both a volumetric and weight basis) to achieve a satisfactory heat release rate. The heat content on a volume basis for a 33% tub-ground pallet/coal blend was 85% of that for the coal, while the 33% green wood chip/coal blend was 61% of that for the coal. This difference in volumetric heat contents required higher gate openings and faster grate and stoker speeds during wood/coal test burns relative to normal boiler operation on coal only.

Emissions/Opacity Flue gas emissions were continuously monitored during the PBC demonstrations with standard process gas analyzers that were installed by FETC. Emissions were low, with average levels of 685 ppm SO_2 and 333 ppm NO_x (corrected to 3% dry O_2) that correspond to about 1.1 lb SO_2/MMBtu and 0.4 lb NO_x/MMBtu. These results were consistent with the low sulfur content of the pallets, while NO_x levels were similar, if not slightly lower, than levels reported for other stoker boilers. A slight reduction in NO_x when firing a biomass/coal fuel is expected given the higher volatile and lower nitrogen content of the pallets as compared to the stoker coal. CO emissions were reasonable with an average 363 ppm (corrected to 3% dry O_2), which is indicative of good combustion, particularly given the load swings and other operational changes, and the fact that the boiler does not utilize any overfire air.

Opacity is monitored continuously by instrument at the NIOSH boilerplant and visually monitored at PBC. Opacity was normal during all the test burns at the NIOSH boiler and during the test burns of the tub-ground pallet fuel blend at the PBC. When a 50% by volume green wood chip blend was tested at the PBC, some smoking was observed, indicating an incomplete combustion of volatiles, perhaps due to high-moisture fuel pieces and/or an uneven distribution of air through the fuel bed. This may represent the upper limit to the percent of green wood that can be used.

WOOD FOR CO-FIRING IN STOKER BOILERS

Types, Sources There are numerous systems for categorizing the types of wood residues. Below is a listing for urban wood residues developed by C.T. Donovan and Associates, Inc[3].

Urban wood residue is composed of highly heterogeneous woods. It is most simply defined as all the wood residue generated within a metropolitan area and may be sub-categorized into urban tree residues and post-consumer wood residue. Urban tree residue consists of residues from tree maintenance, utility right-of-way, and urban site conversion activities. This material is derived mainly from tops, limbs, and whole (small) trees. The material is composed of wood, needles, bark and leaves. Moisture content ranges from 35% to 50%.

Post-consumer wood residue consists of residues derived from secondary wood products. These residues may be further sub-categorized into:

- Pallet and Wooden Container residues – Each year, 16% to 18% of all the timber harvested in the US goes into the manufacture of pallets and wooden containers. Because of their number and bulk, pallets and wooden containers present significant disposal problems and are increasingly collected for reuse or repair. Pallets have a very low moisture content of 5% to 15% and are generally free of paints, stains or other treatments.
- Construction and Demolition (C/D) Wood residues – The wooden components of the debris generated during construction, renovation and demolition of buildings, roads and other structures. The amount of wood in the debris varies from 15% to 85%. 40% of new residential construction residue is believed to consist of wood and wood products. C/D residue wood can be treated or untreated. The wood may also contain laminates and have other waste (such as asphalt shingles, insulation and dry wall) attached. The average moisture content is 12% to 15%.
- Dunnage and Bracing Wood residues – Similar to pallet and wooden container wood residue.
- Urban Secondary Wood Products Manufacturing residues – The residues consist of chips, ends, sawdust, shavings and slabs. The moisture content ranges from 15% to 45%. The residues may contain preservatives, paint, glue and non-wood material such as plastic laminates. Also included are pallet recycling residues. Over 85 million pallets are received for recycling each year. 74% are repaired and reused (or reused without repair); 15% are dismantled for repairs; and the remaining go directly to disposal or are processed for mulch, fuel or fiber.
- Municipal Solid Waste (MSW) Wood residues – All types of urban wood, other than those types listed above, that are conveyed to a landfill for disposal. The average moisture content is 15% to 25%.

Characteristics Although the heat content for all hardwoods is approximately 8,500 Btu/lb on a moisture, ash-free basis (MAF) and MAF softwood has a heat content approaching 9,500, the physical and chemical characteristics of wood residue varies widely depending on the type and source of the material. The most important characteristics of wood as it relates to its use as a fuel in stoker boilers are (i) moisture content, (ii) ash characteristics, (iii) post-harvest treatment/contamination, (iv) particle size/fuel blending, and (v). price/availability

Moisture Content: The moisture content for freshly harvested "green" wood is approximately 50%. Over time the moisture content declines to between 5% and 15%. The high moisture content of green wood poses several problems related to its use as fuel: (1) It represents a weight with no caloric value that can increase the transportation and handling cost. (2) It will increase the volume of flue gas generated in combustion requiring an increase in draft fan output. (3) It will lower the furnace exit temperature, which will lower the heat transfer rate in the connective sections of the boiler. (4) It will lower the heating value of the fuel due to un-recovered energy in the flue gases that represents the heat used to vaporize the moisture in the fuel. Stoker boilers are designed for a given fuel moisture content (and fuel size distribution). Usually moisture content should be kept within 10% of design.

Ash characteristics: One of the major concerns associated with adding a biomass co-firing fuel to a boiler originally dedicated to coal firing is the possibility for a change in the ash fusion characteristics of the blended fuel. In a properly operating chain-grate stoker boiler, the individual ash particles fuse together in a porous mass that permits he passage of air and allows for uniform combustion across the bed. Adding wood to the coal has had a deleterious effect on the slagging and fouling characteristics with certain wood/coal fuel blends.

The clear stemwood of most species of trees contains very little ash, generally less than 1%. Stemwood is the inner wood from the trunk and larger branches. Actively growing portions of a tree such as the leaves and inner bark are higher in ash and the ash is high in "alkali" content. Alkali content refers to the sum of the potassium oxide (K_2O) and sodium oxide (Na_2O) in the ash. This high alkali content is the source of many of the problems with biomass ash.

Using indices originally developed to predict coal ash behavior, the elemental ash analyses of bottom and fly ashes from a stoker boiler burning Eastern Kentucky compliance coal, and published data on hardwood and urban wood residue ashes, mathematical predictions of the ash characteristics for two possible 20% wood / 80% coal fuel blends were calculated. The results of the comparisons indicate that the combustion on the grate of either urban wood residues or hardwood alone would likely cause severe fouling problems and a possible slagging problem. These calculations also indicate that slagging and fouling should not be a problem when co-firing urban wood residues at 25% mass input with compliance coal in stoker boilers. Slagging and fouling problems were not observed during any of the demonstration test burns.

Post-harvest treatment/contamination: Treatment may be as a (1) surface coating (paint, stain, etc.), (2) manufacturing agent such as resin, glue, or binder used as adhesive; or (3) impregnated preservative. The treatments which cause the greatest environmental concern in relation to their combustion are chromated copper arsenate (CCA) pressure treated lumber and lead-based paint. Wood with these treatments may be found in C/D wood, and makes the uses of C/D problematic. The most common type of contamination is dirt. Dirt will be found in the bark of harvested wood and urban wood residues. Dirt can have a negative impact on the slagging and/or fouling behavior of the ash. Much of the contaminating dirt can be removed by screening out the fines.

Particle size/fuel blending: Stoker boilers are designed for a given fuel size distribution. The wood provided to the first PBC and the NIOSH cofiring demonstration was refined tub-ground mulch. A tub grinder shatters the wood to produces a splinter material. This material is stringy with frayed ends and is subject to bridging at the delivery grill. When a wood chip produced from green whole-tree stems was tested at the PBC, no bridging was observed even when mixed to over 40% wood by volume. The superior behavior at the delivery grill of a wood chip is due to the chip's more cubic shape and sharp, knife-cut edges. Unfortunately, urban wood waste with nails and other hard contaminates causes rapid wear on a wood chipper's knife blades. Therefore, chippers cannot be used for primary size-reduction.

Three methods of fuel blending have been used in the demonstrations: mixing on the ground using a front-end loader, layering on the bed of the delivery truck and mixing in a FECON blender. Mixing with front-end loaders can produce a homogeneous fuel blend but the process generally creates excessive fines. Layering on the bed of truck can be sufficient to produce a reasonably uniform mixture on the grate if the layering is performed with care. In the first PBC demonstration, uniform layers several feet thick were found to pass through the delivery grill and reach the boiler grate mixed in a manner indistinguishable from the blends made on the ground. In the NIOSH demonstration, less care was used in layering the fuels in several deliveries and the wood formed large clumps on the delivery grill. These clumps interrupted the delivery and were never completely mixed into the coal by the boilerhouse conveyances. Wood and coal were simultaneously loaded into a FECON blender to produce a very uniform blend. The blend retained its consistency through the boilerhouse conveyances onto the boiler grate. However, the frayed ends of the tub-ground wood led to occasional interruptions of flow through the delivery grill of even the well-blended mixtures.

Price/availability. In order for a wood/coal fuel blend to gain commercial success it must be offered to the boilerplant at a cost equal to or below the plant's current cost of coal. Size reduction is the major cost in marketing urban wood residues as a boiler fuel. The processing costs for a commercial operation are expected to be approximately $20 per ton. This is only marginally less than a wood processor can receive for the product from a coal vendor. In the current market in order to make wood to stoker boiler fuel processing profitable, the wood processor must capture a tipping fee for the waste residues that are collected. In 1996 at the beginning of the University's research program, wood processors in the Pittsburgh region were receiving a tipping fee for pallet wastes that they were tub grinding to produce a colored-mulch. Since then the highly profitable color-mulch market has expanded and all the readily available pallet residue is being collected for processing to colored-mulch without a tipping fee.

Nationally, it is estimated that 43.8 million tons of C/D waste are generated each year with 24.5 million tons available for cofiring[4]. This material is currently being landfilled with a tipping fee in the Pittsburgh region of approximately $30 per ton. Regionally this amounts to more than 125,000 tons per year.

CONCLUSIONS /FUTURE PLANS

While working toward the introduction in western Pennsylvania of commercial cofiring fuel for stoker boilers, the University has learned much about the problems associated with seeking specific sources of urban waste wood and its processing into boiler fuel. The project team has concluded that use of a properly prepared blend of processed pallet residue and coal as stoker fuel with up to 12% wood by BTU content is technically feasible and environmentally desirable. Unfortunately in the Pittsburgh region pallet residue will not be available for processing to a stoker boiler cofuel. C/D wood residue will be required for the fuel blend.

In future planned demonstrations, the University will use C/D wood for the wood component of the fuel blend. ACHD has been supportive of the use of pallet residue as a cofiring fuel and has readily granted air quality variances for the demonstrations. Improperly source-segregated C/D wood has the potential of being contaminated with material that will cause toxic air emissions when combusted. The University and the wood processor plan to develop a quality assurance plan that will satisfy ACHD that the fuel is free of hazardous contamination. If a variance is granted to burn construction wood, then the University, through local builders organizations, will locate construction contractors that wish to supply source-segregated construction wood (and avoid a portion of their normal waste tipping fee for this material). The wood processor will locate a roll-off container at one or more of these sites. If a variance is also granted to burn demolition wood then wood processor will locate roll-offs at one or more demolition sites identified by the University with the aid of the Pennsylvania Department of Environmental Protection. The emissions from demolition waste combustion will be monitored for lead, arsenic and chromium.

Although standard tub-ground wood has been acceptable in the boiler as the wood component of the cofiring fuel at some boilerplants, the bridging it causes at the delivery grill will be unacceptable at most plants. For future demonstration the wood processor will develop two methods for producing a "chip" from urban wood waste. In the first method the processor will extend the work started for the second PBC demonstration on producing chip-like mulch from tub grinding. The processor will install a cut-off plate behind an over sized screen on the tub grinder that will sheer off the long wood splinters to a more cubic wood fragment than is normally produced. The wood will be sized to 1¼ inch by ¼ inch. In the second method, the wood will be very briefly tub ground to liberate the nails. Passing the wood through a standard knife-bladed chipper will follow this tub grinding. The wood will be sized to 1½ inch by ¼ inch.

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